

Practical Applications of Capillary Extrusion Rheometry to Energetics Processing Problems

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Characteristics of Energetics

- **Multiphase systems – can contain:**
 - **Binders (Polymer Matrix – energetic & non-energetic)**
 - **Fillers (eg HE)**
 - **Plasticizers (energetic & non-energetic)**
 - **Stabilizers**
 - **Ballistic Modifiers (eg tin salts for DB)**
 - **Process Aids (solvents, waxes)**

These complex materials can confidently be expected to exhibit complex processing characteristics.



Typical Processing Operations

- **Mixing**
- **Casting**
- **Pressing (moulding)**
- **Extrusion**
- **Machining**

Processing involves deformation → FLOW



Variables of Processing

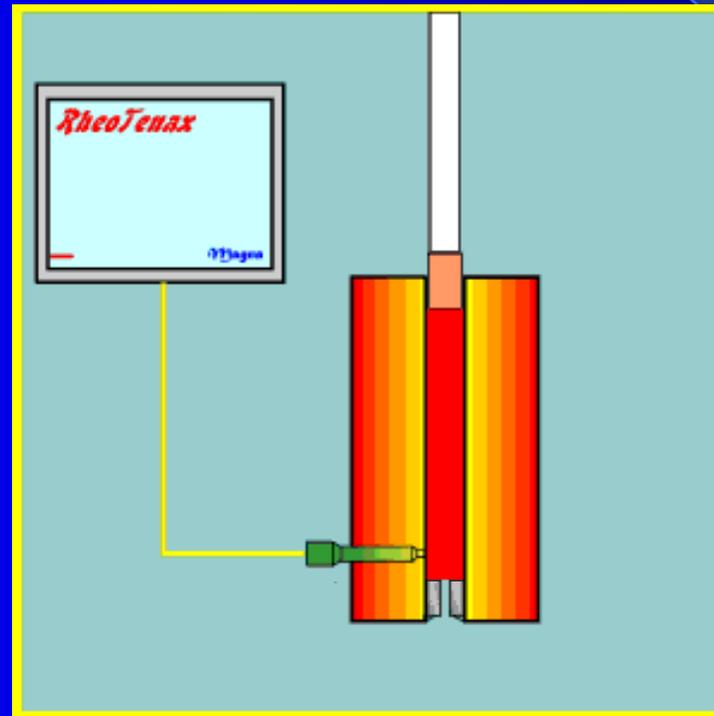
- **Speed / Rate**
- **Time**
- **Temperature**
- **Pressure/Force/Load/Torque (= Stress)**
- **Energy Input**

Processing involves deformation → FLOW

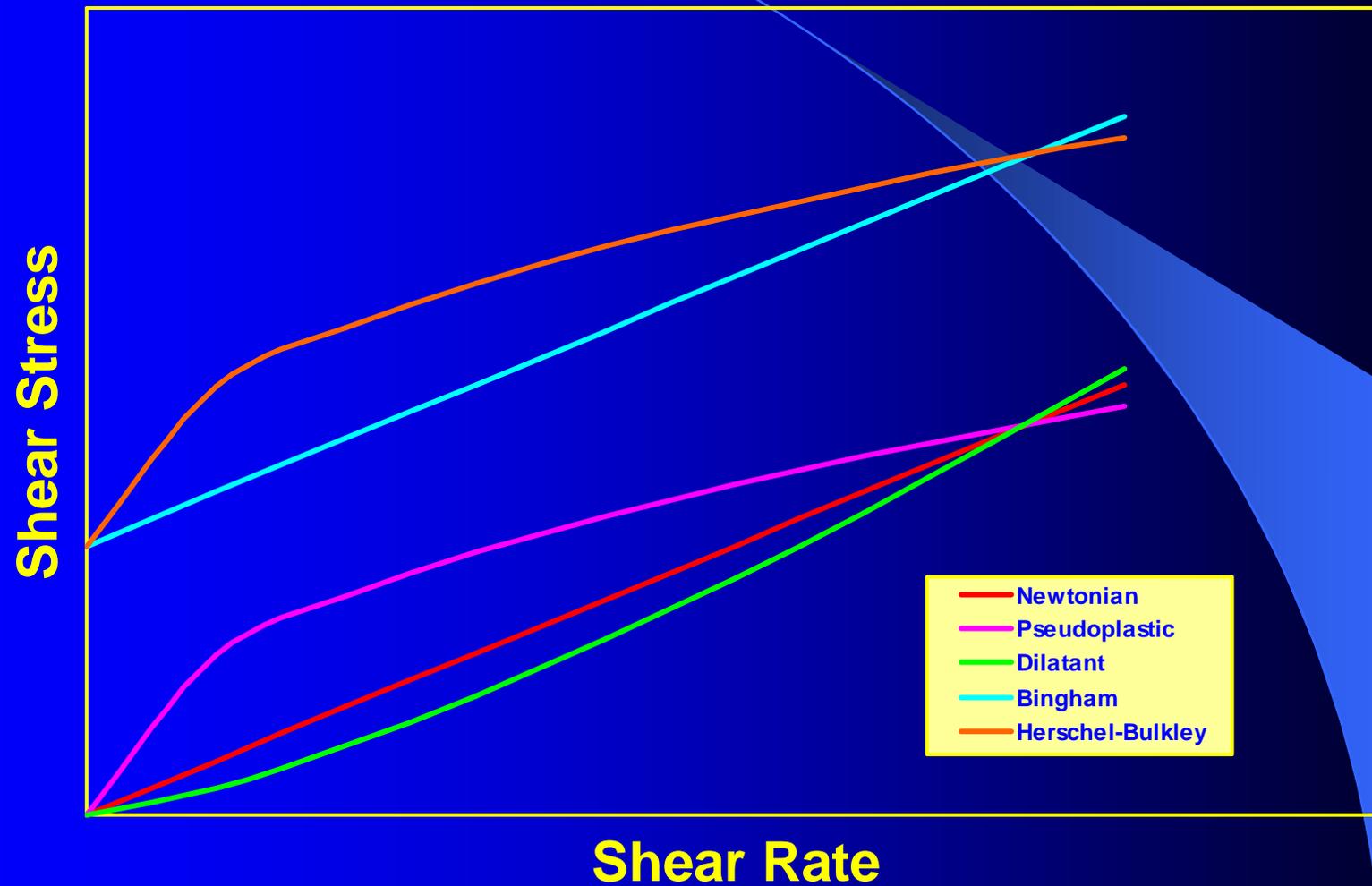


Capillary Extrusion Rheometer

Principle of Operation



Shear Flow Types



Capillary Extrusion Rheometers

Pros

- **Controlled conditions**
- **Small samples**
- **Wide range**
- **Good process mimic**
- **Can test extrudate further**
- **Well developed theory**
- **Shear & extensional**

Cons

- **Can't see time-dependence**
- **Large particles block orifice**
- **Need to ensure that sample is representative**



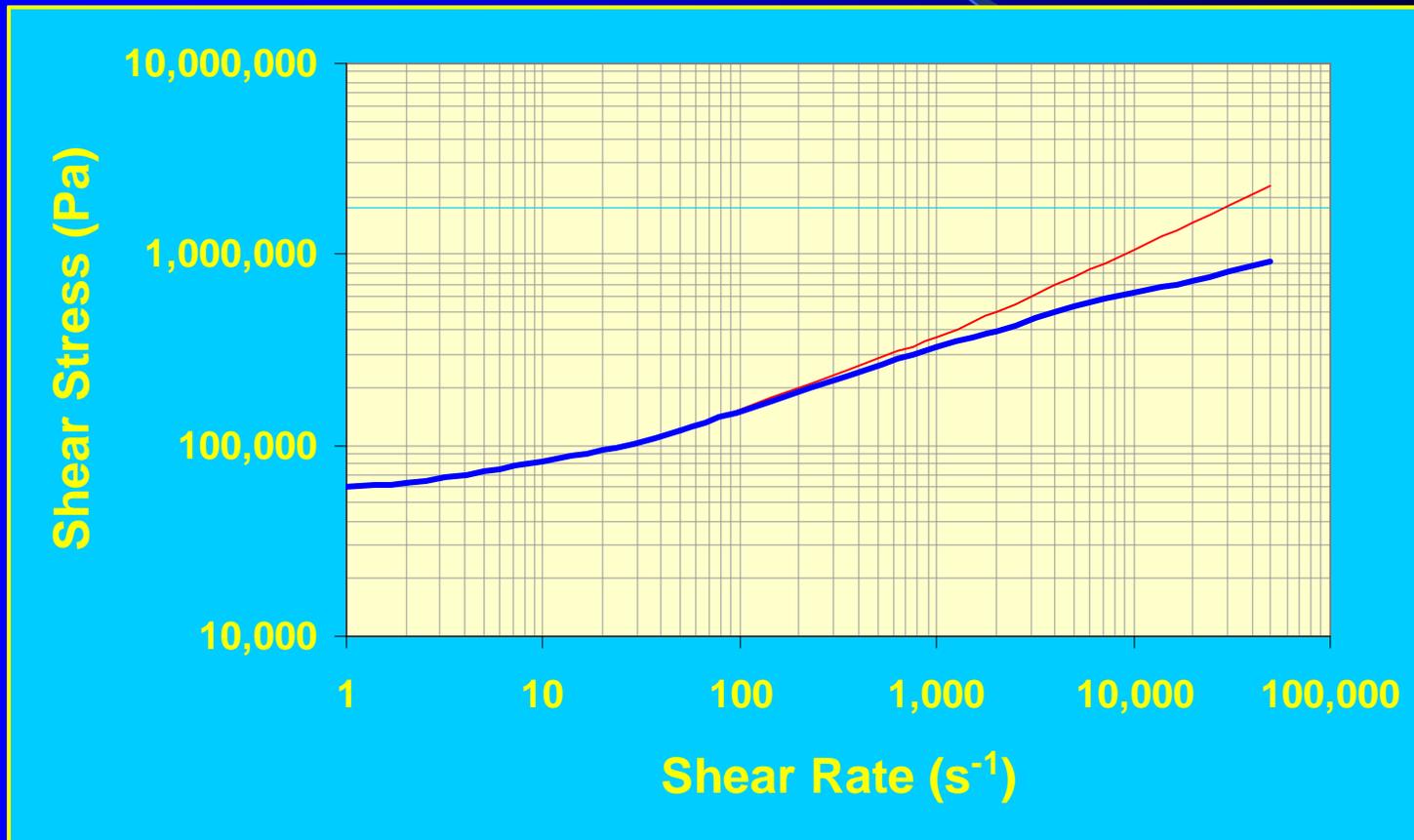
Capillary Extrusion Rheometers

Detectable Parameters & Phenomena

- Shear viscosity
- Extensional viscosity
- Power Law behaviour & other models
- Yield stress – Bingham or Herschel-Bulkley
- Wall Slip
- Extrudate swell
- Viscous heating
- Pressure coefficient of viscosity
- Melt Fracture, Sharkskin etc



Typical Flow Curve for a Triple-Base Gun Propellant Dough



Safety Considerations For Use With Energetics

- **Stainless steel construction (largely)**
- **Non-sparking materials**
- **Remote control operation**
- **Electronics via Safety Barriers**
- **CCTV surveillance (with sound)**
- **Interlocked controls**
- **Externally-threaded die retainer**
- **No blind holes or cracks**
- **Compatible materials**
- **Remote manual ram retraction**
- **Mercury-free pressure transducers**



BFR 2100 Capillary Extrusion Rheometer



Extrusion Head & Remote Control Room



BFR 2100

Capillary Extrusion Rheometer

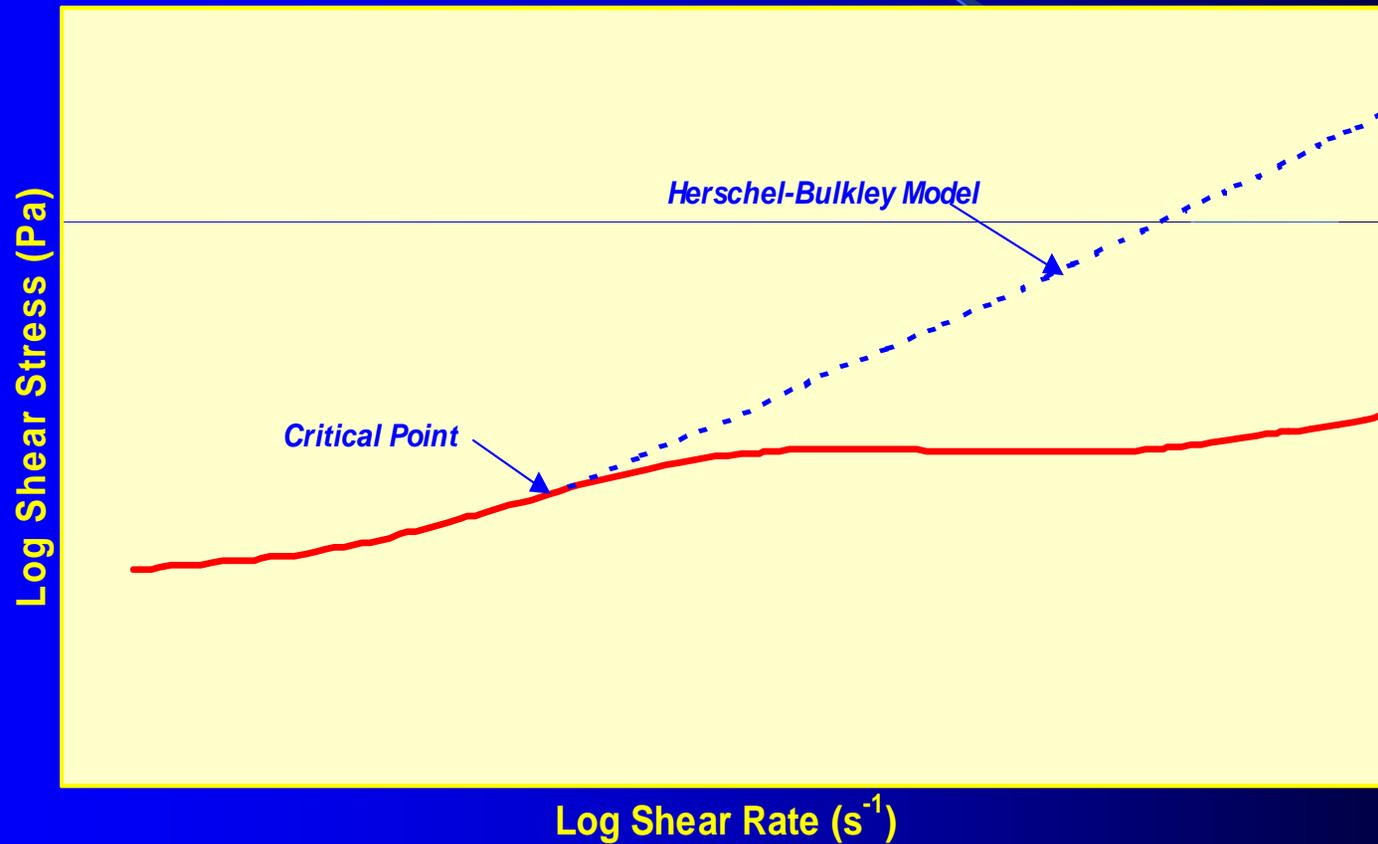


**Extrusion Head, Laser Micrometer &
IR Pyrometer**

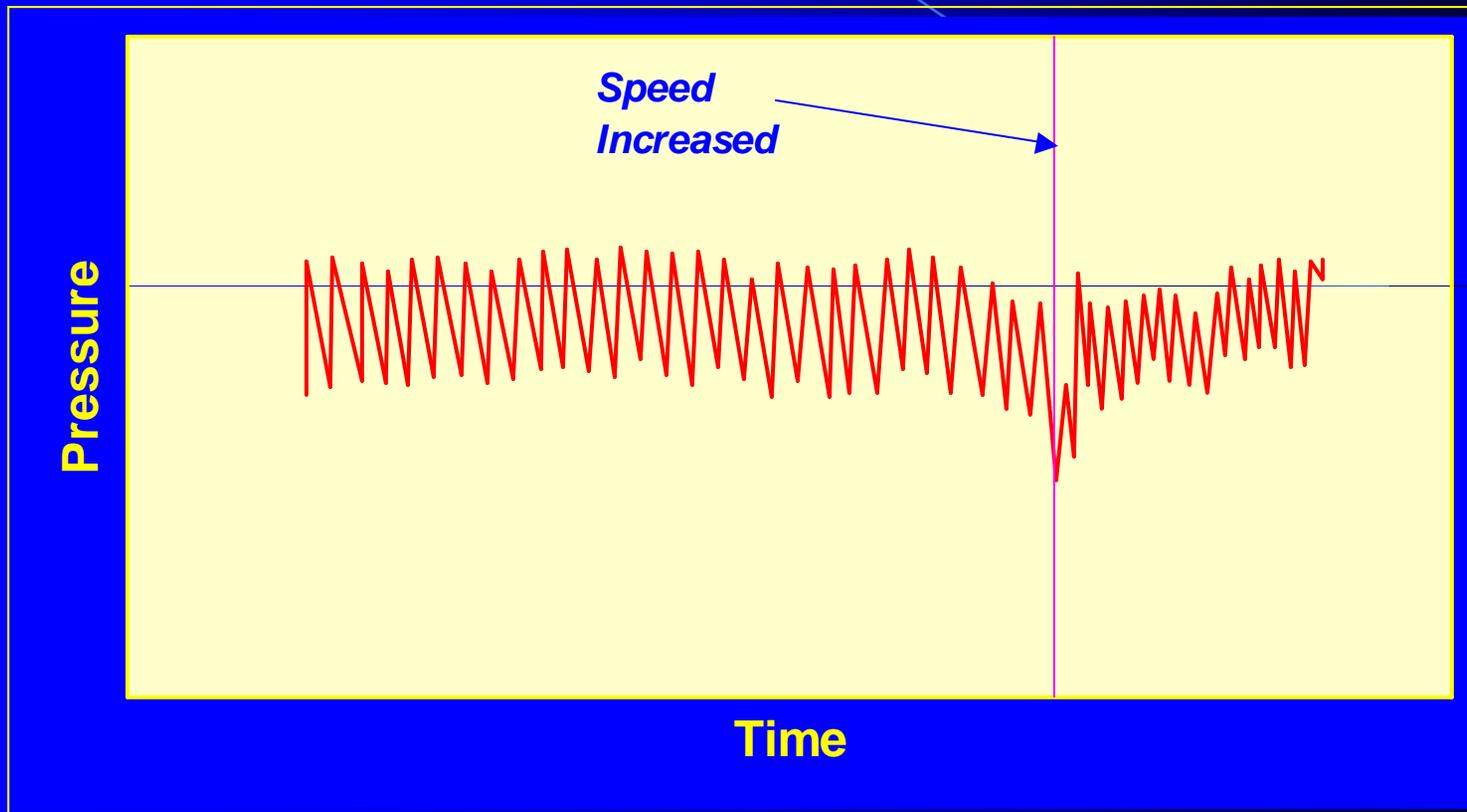
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Typical Wall-Slip Curve

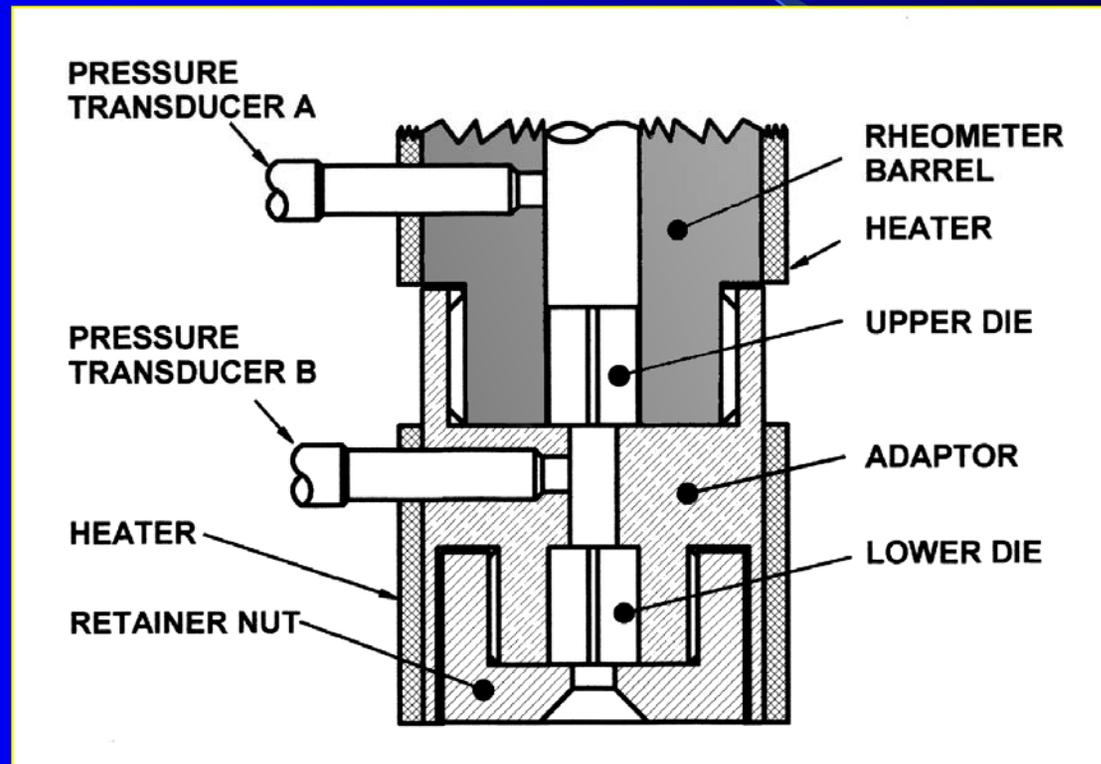


Stick-Slip

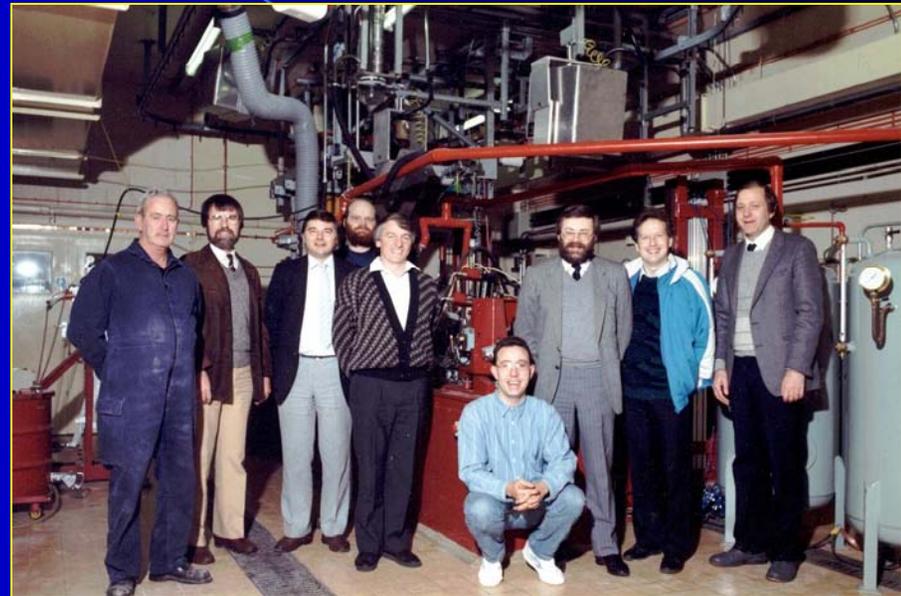
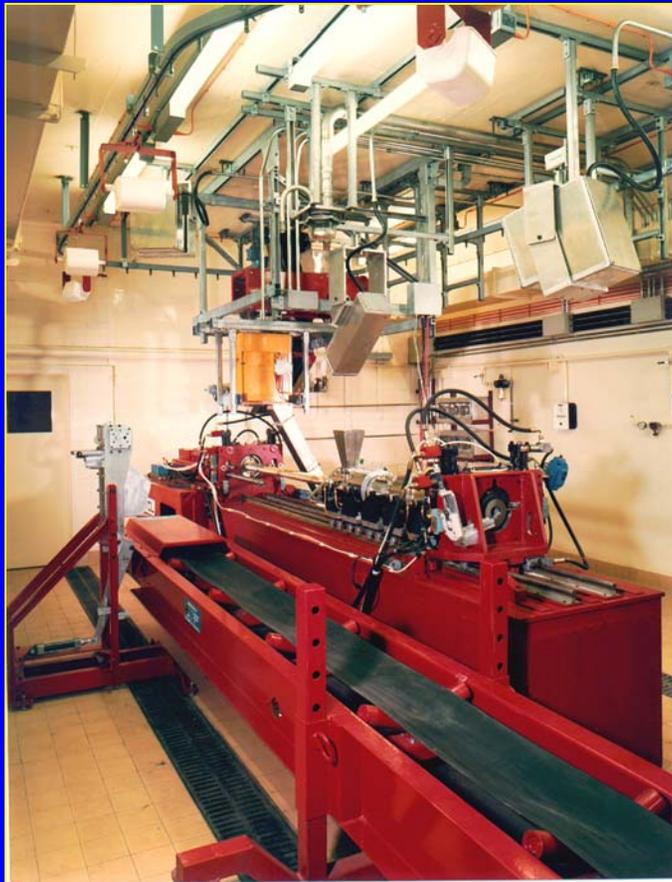


PCV

Pressure Coefficient of Viscosity Adaptor



Twin-Screw Extruder



...designed using
capillary extrusion
rheometer data



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Conclusions

Capillary Extrusion Rheometry allows:

- ✓ **Energetic materials to be characterised in considerable depth and detail**
- ✓ **Dangerous materials to be tested safely**
- ✓ **Dies to be optimised**
- ✓ **Processing to be simulated**
- ✓ **Formulations to be developed**
- ✓ **New processes to be designed**

